

Status and future prospects for CLFV searches at BESIII

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Here we present the latest results of the charged Lepton Flavor Violation process searches at the BESIII experiment in the decay of $J/\psi \rightarrow e\mu$, using $(225.3 \pm 2.8) \times 10^6$ J/ψ events collected with the BESIII detector at the BEPCII collider. An upper limit on the branching fraction of $\mathcal{B}(J/\psi \rightarrow e\mu) < 1.6 \times 10^{-7}$ (90% C.L.) is obtained. The prospects and challenges with the future data are also discussed based on MC simulation.

1 Introduction

As is well known, the Lepton Flavor Violation (LFV) is highly suppressed in the prediction of Standard Model (SM) by the finite but tiny neutrino masses. Its branching fraction is calculated to be at a negligible level and so far none has been found in all the historical experiments. However, there are various theoretical models which can enhance the LFV effect large enough to be detected by the present experiments. Such as the SUSY grand unified theory¹, SUSY with a right-handed neutrino², gauge-mediated SUSY breaking³, SUSY with vector-like leptons⁴, SUSY with R-parity violation⁵, models with Z^6 , or models with Lorentz non-invariance⁷. Therefore, detection of such LFV decays could be taken as distinct evidence for new physics.

Experimentally, the search for LFV effect has been carried out in many ways, including lepton (μ, τ) decays, pseudoscalar meson (K, π) decays, vector meson ($\phi, J/\psi, \Upsilon$) decays, etc. For example, a recent measurement based on $\mu^+ \rightarrow \gamma e^+$ performed by the MEG Collaboration yields an upper limit of $\mathcal{B}(\mu^+ \rightarrow \gamma e^+) < 2.4 \times 10^{-12}$ ⁸, and a similar searching in τ decay by the BABAR Collaboration reports $\mathcal{B}(\tau^+ \rightarrow \gamma e^+) < 3.3 \times 10^{-8}$ ⁹. Moreover, for neutral kaon and pion decays, the current results are $\mathcal{B}(K_L^0 \rightarrow \mu^+ e^-) < 4.7 \times 10^{-12}$ ¹⁰ produced by the E871 Collaboration and $\mathcal{B}(\pi^0 \rightarrow \mu^+ e^-) < 3.8 \times 10^{-10}$ ¹¹ by the E865 Collaboration. For LFV decays of vector mesons, despite having just collected relatively small data samples, evidences with better signal-significance have been observed, thanks to the simple background components. The best measurement in ϕ decay, based on the data sample of 8.5 pb^{-1} at the e^+e^- annihilated energy region $\sqrt{s} = 984 - 1060 \text{ MeV}$, is obtained by the SND Collaboration in 2010 setting upper limit of $\mathcal{B}(\phi \rightarrow \mu^+ e^-) < 2.0 \times 10^{-6}$ ¹². In bottonium systems, based on about 20.8 million $\Upsilon(1S)$ events, 9.3 million $\Upsilon(sS)$ events, and 5.9 million $\Upsilon(3S)$ events accumulated with the CLEO-III detector, the CLEOIII Collaboration presented the most stringent LFV upper limit of $\mathcal{B}(\Upsilon(1S, 2S, 3S) \rightarrow \mu\tau) < \sim 10^{-6}$ ¹³. In charmonium systems, the BESII Collaboration obtained $\mathcal{B}(J/\psi \rightarrow \mu e) < 1.1 \times 10^{-6}$ ¹⁴, $\mathcal{B}(J/\psi \rightarrow e\tau) < 8.3 \times 10^{-6}$ and $\mathcal{B}(J/\psi \rightarrow \mu\tau) < 2.0 \times 10^{-6}$ ¹⁵ by analysing a data sample of 58 million J/ψ events collected with the BESII detector, which are the best current upper limits on LFV effect in charmonium meson decays. In this talk, we introduce the latest result from the BESIII Collaboration of searching for charged Lepton Flavor Violation decays based on about 225 million J/ψ events¹⁶ collected at the BESIII detector.

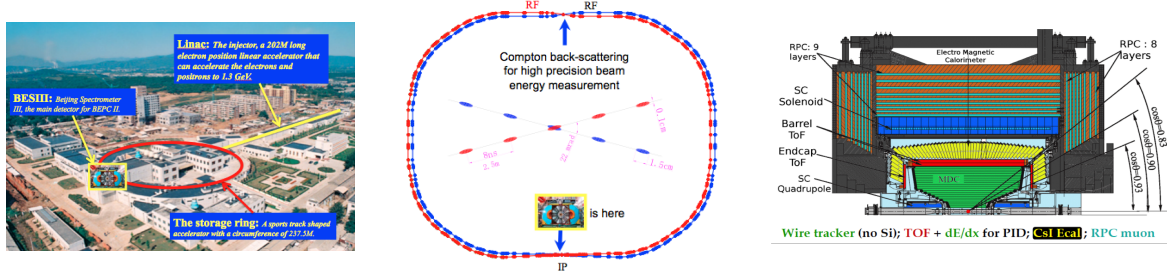


Figure 1 – Illustration for the birdview of the experiment(left), the storage ring (center) and the detector (right)

2 The Detector and Simulation

The BESIII experiment is composed of the LINAC, the BEPCII collider, and the BESIII detector¹⁷ (Fig. 1), which is a large solid-angle magnetic spectrometer with a geometrical acceptance of 93% of 4π . It has four main components: (1) A small-cell, helium-based (40% He, 60% C_3H_8) main drift chamber (MDC) with 43 layers providing an average single-hit resolution of $135 \mu m$, charged-particle momentum resolution in a 1.0 T magnetic field of 0.5% at 1.0 GeV, and a ionization energy loss information (dE/dx) resolution better than 6%. (2) A time-of-flight (TOF) system constructed of 5 cm thick plastic scintillators, with 176 detectors of 2.4 m length in two layers in the barrel and 96 fan-shaped detectors in the end-caps. The barrel (end-cap) time resolution of 80 ps (110 ps) provides a 2σ K/π separation for momenta up to ~ 1.0 GeV. (3) An electromagnetic calorimeter (EMC) consisting of 6240 CsI(Tl) crystals in a cylindrical structure (barrel) and two end-caps. The energy resolution at 1.0 GeV is 2.5% (5%) and the position resolution is 6 mm (9 mm) in the barrel (end-caps). (4) The muon system (MUC) consists of 1000 m^2 of Resistive Plate Chambers (RPCs) in nine barrel and eight end-cap layers and provides 2 cm position resolution.

The event selection and the estimation of backgrounds are optimized through Monte Carlo (MC) simulation. The GEANT4-based simulation software BOOST¹⁸ includes the geometric description and material composition of the BESIII detector and the detector response and digitization models, as well as the tracking of the detector running conditions and performance. The generic simulated events are generated by e^+e^- annihilation into a J/ψ meson using the generator KKMC¹⁹ at energies around the center-of-mass energy $\sqrt{s} = 3.097$ GeV. The beam energy and its energy spread are set according to the measurement of the BEPCII, and the initial state radiation (ISR) is implemented in the J/ψ generation. The decays of the J/ψ resonance are generated by EVTGEN²⁰ for the known modes with branching fractions according to the world's average values²¹, and by LUNDCHARM²² for the remaining unknown decays.

3 Result of $J/\psi \rightarrow e\mu$

At the BESIII experiment, the signal events are produced as $e^+e^- \rightarrow J/\psi$ at $\sqrt{s} = 3.097$ GeV, and then $J/\psi \rightarrow e\mu$, where the signal tracks are back-to-back opposite charged tracks with no extra EMC showers. The details of the event selection can be found in Ref.ref::bes3-emu. Based on a full simulation to the physics around the J/ψ resonance, we found most of the backgrounds are from $J/\psi \rightarrow e^+e^-$, $J/\psi \rightarrow \mu^+\mu^-$, $J/\psi \rightarrow \pi^+\pi^-$, $J/\psi \rightarrow K^+K^-$, $e^+e^- \rightarrow (\gamma)e^+e^-$ and $e^+e^- \rightarrow (\gamma)\mu^+\mu^-$, in which one or more tracks are misidentified as muon or electron. To suppress these contamination events, several powerful criteria are employed.

For e^+/e^- identification, there must be no associated hit in the MUC and the value of E/p is required to be greater than 0.95 and less than 1.5, where E is the energy deposited in the EMC and p is the momentum measured by the MDC. The absolute value of $\chi_{dE/dx}$ from the dE/dx measurement with electron hypothesis should be less than 1.8. Electron, muon, pion and kaon samples are simulated with MC method to investigate the above cut values, which are shown

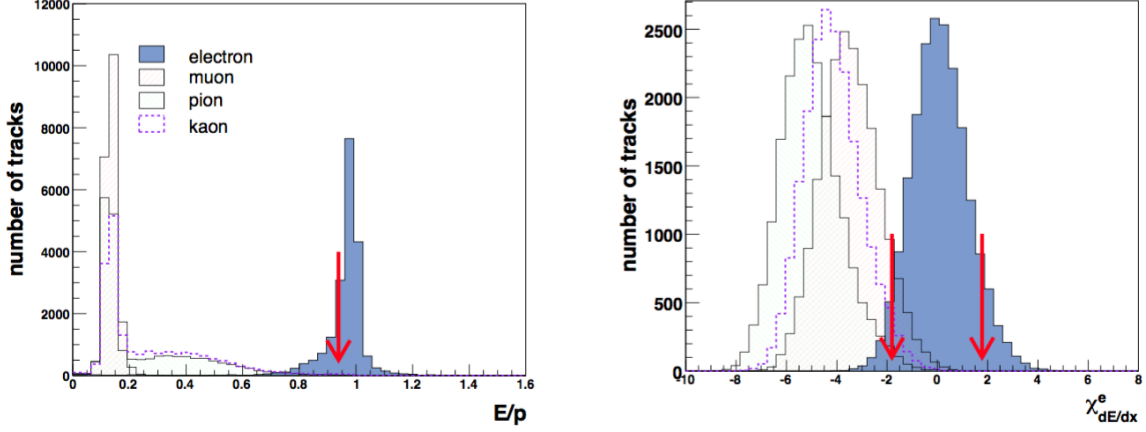


Figure 2 – The distributions of E/p (left) and $\chi^2_{dE/dx}$ (right) for the simulated electron, muon, pion and kaon samples.

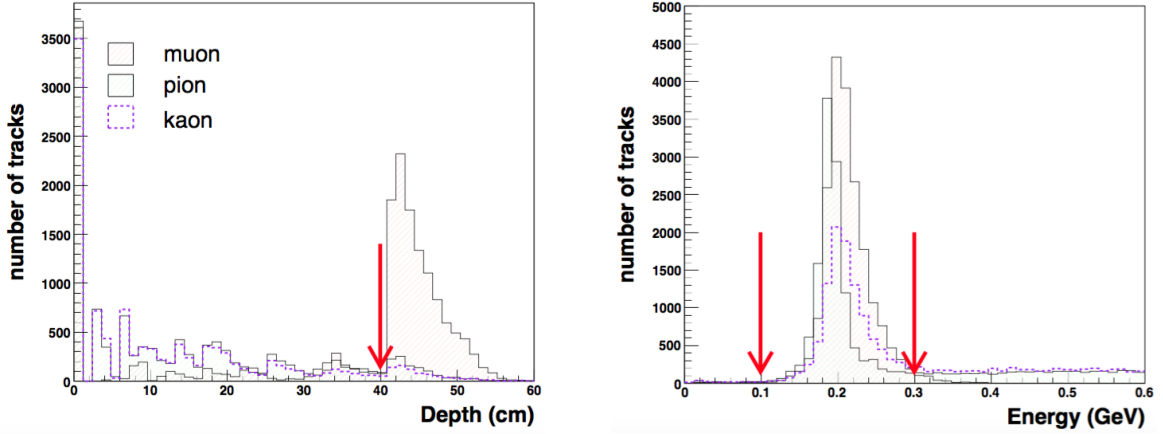


Figure 3 – The distributions of the penetration depth in the MUC (left) and the deposited energy in the EMC (right) for the simulated muon, pion and kaon samples.

in figure 2, where the E/p and $|\chi^2_{dE/dx}|$ distributions of electron can be well discriminated from other particles.

For $\mu + \mu^-$ identification, the charged tracks in the active area of the barrel MUC ($|\cos \theta| < 0.75$) are required to have a E/p value less than 0.5, and the deposited energy in the EMC between 0.1 GeV and 0.3 GeV. In order to remove those tracks which are poorly reconstructed in the MUC, we require the penetration depth in the MUC larger than 40 cm and χ^2 of track fitting in the MUC should be less than 100 if the track penetrates more than 3 detecting layers in the MUC. Furthermore, the $\chi^2_{dE/dx}$ value from the dE/dx measurement with electron hypothesis must be less than -1.8. With the above simulated samples, distributions of the deposited energy in the EMC and the penetration depth in the MUC are shown in figure 3, we can suppress the misidentification from pion and kaon with this two information.

After the above analysis, surviving events of $J/\psi \rightarrow e^+ \mu^-$ are examined with two variables, $|\Sigma \vec{p}|/\sqrt{s}$ and E_{vis}/\sqrt{s} , where $|\Sigma \vec{p}|$ is the vector sum of the total momentum in one event, E_{vis} is the total reconstructed energy, and \sqrt{s} is the center-of-mass (c.m.) energy. A candidate event should be located in the signal box defined by $0.93 \leq E_{vis}/\sqrt{s} \leq 1.10$ and $|\Sigma \vec{p}|/\sqrt{s} \leq 0.10$, which corresponds to about 2 standard deviations of the variables determined by MC simulation.

Finally, 4 candidate events in the signal region are obtained from 225 million J/ψ meson decays, which are shown in figure 4. The detection efficiency for signal is determined to be (18.99 ± 0.12)%. Based on a full simulated J/ψ MC sample whose size is 4 times of our experimental data, we find nineteen background events surviving in the signal region. This yields a predicted

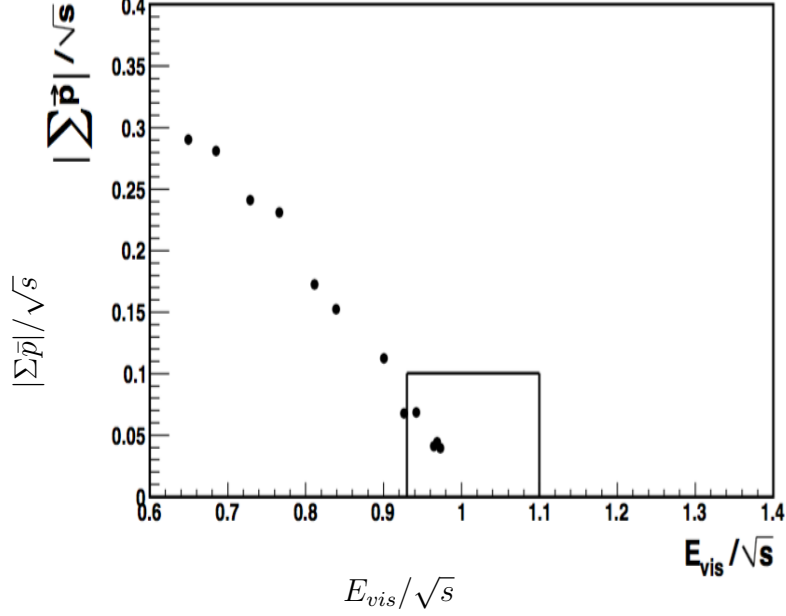


Figure 4 – The scatter plot of E_{vis}/\sqrt{s} versus $|\Sigma \vec{p}|/\sqrt{s}$ for J/ψ data. The signal region, defined by $0.93 \leq E_{vis}/\sqrt{s} \leq 1.10$ and $|\Sigma \vec{p}|/\sqrt{s} \leq 0.1$, is shown as a box.

background of $N^{exp} = (4.75 \pm 1.09)$.

Considering the fact that only four events survived in signal region which is consistent with the number of potential backgrounds, the pure signal events should be quite poor. Therefore, we set the upper limit on the branching fraction of $J/\psi \rightarrow e\mu$ based on the Feldman-Cousins method in which systematic uncertainties have been incorporated. The upper limit on the number of observed signal events at 90% C.L. is obtained to be 6.15 by the POLE program[?] inputting the number of expected background events, the number of observed events and the systematic uncertainty (5.84%). The upper limit on the branching fraction is determined to be $\mathcal{B}(J/\psi \rightarrow e\mu) < 1.6 \times 10^{-7}$.

4 Prospects

Here we make a full simulation to estimate the prospects of searching for cLFV signals in $J/\psi \rightarrow e\tau$ and $J/\psi \rightarrow \mu\tau$ based on the 1300 million J/ψ sample. The tracks in the final states of $J/\psi \rightarrow e\tau$ and $J/\psi \rightarrow \mu\tau$ are the same despite the momentum distribution, both have two opposite charge tracks and two missing tracks, so the analysis procedure of the two decays are similar. By analyzing the generic MC sample of J/ψ decay, we can found most of the backgrounds for the two decay modes are from $J/\psi \rightarrow \pi^+ K_L K^-$, $J/\psi \rightarrow K_L K_L$, and $J/\psi \rightarrow K^{*0} K^0$. After background suppression, the detection efficiency is estimated to be 14% and 19% for $J/\psi \rightarrow e\tau$ and $J/\psi \rightarrow \mu\tau$, respectively. The sensitivities of the branching fraction are obtained to be $\mathcal{B}_{J/\psi \rightarrow e\tau}^{sensitivity} < 6.3 \times 10^{-8}$ and $\mathcal{B}_{J/\psi \rightarrow \mu\tau}^{sensitivity} < 7.3 \times 10^{-8}$ at 90% C.L. with similar calculation method used in $J/\psi \rightarrow e\mu$.

5 Summary

In summary, by analyzing 255 million J/ψ data collected at the BESIII detector at the BEPCII collider, the charged Lepton Flavor Violation process is searched. Four signal events are observed which are consistent with the background estimation. As a result, we got the best upper limit in the world on the $J/\psi \rightarrow e\mu$ branching fraction at a 90% CL. To get the prospects based on 1300 million J/ψ data which has been accumulated by the BESIII experiment, we make a full

MC simulation. The sensitivities on searching for cLFV signals in the $J/\psi \rightarrow e\tau$ and $J/\psi \rightarrow \mu\tau$ decays are estimated to be 6.3×10^{-8} and 7.3×10^{-8} at 90% C.L., respectively, which will be the world best constraints.

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